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CONSTRAINTS ON ELECTRONIC MAP PRESENTATION AND TERRAIN DEPICTION FOR AIR-GROUND TARGETING: THE THREE MAP PROBLEM

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14. ABSTRACT
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Constraints On Electronic Map Presentation And Terrain Depiction For

Air-Ground Targeting: The Three Map Problem

Abstract

Seventeen pilots performed a flight simulation in which they flew toward a designated ground target, navigating across three legs and finally capturing the target. While they consulted the forward view depicted on an Evans and Sutherland display, two different means of presenting the terrain as an electronic map on an IRIS display were contrasted. In the "tiled "method, the terrain was depicted by three 3D exocentric maps, covering the distance between start and the final target, like three overlapping tiles. In the "global-local" method, the depiction showed three maps, progressively increased in detail (more local coverage, less global coverage), by presenting only the remaining course between the initiation and final target destination. Pilots flew through (and located the target within)either sparse or dense terrain, and the target was defined by either cultural or natural features.

The results revealed general equivalence between the two map presentation types, but a slight difference in favor of the global-local coverage, despite the fact that pilots preferred the tiled coverage because of its consistency of scale. Target search was superior in sparse terrain, whereas lateral tracking error, representing navigational performance, was superior in denser terrain, because of the greater richness of information upon which to base map vs. forward-view comparisons. There were no pronounced differences between cultural and natural features.

Introduction

Navy air to ground attack missions must be supported by careful guidance to a remote location. Such guidance is typically supported by a map and, increasingly, this map may be an electronic rendering of computer generated imagery, or uplinked satellite imagery.

The high speed at which such missions are flown, imposes two kinds of constraints, one technological and one related to human performance. On the technological side, bandwidth constraints may allow only a limited amount of image information (bits) to be transmitted to the aircraft in real time, to specify routing and target characteristics. On the human performance side, the high speed of ingress leaves little time available for pilot or navigator to compare features of the imagery, with features viewed on the terrain below, to establish that the route is being flown correctly, and ultimately to confirm that the sighted target is the same as that designated, either by the imagery, or by verbal description. In order that the second constraint is satisfied, it is necessary to render the imagery in such a way that it is most congruent with the pilot (or navigator's) forward field of view of the terrain ahead and below the aircraft. In this way congruence of the two images can be established in minimum time (Hickox and Wickens, 1996; Schreiber et al., 1998, in press).

In previous research under this contract, we have identified the time and accuracy costs of cognitive transformations required when the map imagery and the forward view do <u>not</u> correspond in various ways. For example, Schreiber et al. (1998, in press) established that the costs of lateral mental rotation were non-trivial, when aircraft heading was incongruent with map orientation. Hickox and Wickens (1996) established the time costs of vertical mental rotation, when the elevation angle depicting the map imagery did not correspond to the slant angle by which the pilot viewed the forward terrain. In both cases, the costs were non trivial, leading to delays as long as 2-3 seconds (allowing a substantial distance of flight at high speeds), and increased error rates. The latter in particular are of concern, because a pilot's error in this process can lead to either a failed or delayed navigational mission (if the desired ingress route is lost), or attack of the wrong target.

In addition to establishing the importance of costs of vertical rotation, and therefore the importance of 3D congruence between map and forward field of view, Hickox and Wickens' (1996) investigation revealed two additional factors that influenced the comparison process. They found that increases in the <u>complexity</u> of the visual field retarded the process; as pilots apparently needed to search and compare a greater number of scene features, in order to assure congruence. They also found that scenes containing a greater proportion of <u>cultural</u> features, like roads and buildings, supported more rapid comparisons, than those containing predominately natural features.

Hickox and Wickens employed a paradigm in which pilots compared static images. However, Conejo and Wickens (1997, 1998) extended the paradigm to one more directly simulating the ingress of an air-ground attack mission. While their interests

focused on target cueing, rather than map rendering, they also examined a comparison between cultural and natural features. The investigators distinguished between lead in features ***to*** the target, and the features ***of*** the target itself. They found that best performance appeared to result from a combination of cultural and natural features, when one feature type defined the target, and the other characterized the lead-in. Thus the actual role of feature type appears to be somewhat complex.

In the same manner, it can be hypothesized that the role of image complexity can also be complex. While it is indeed true that more complex images require longer to search (e.g., in order to locate a target, or establish congruence), it is also the case that more complex, information rich terrain can offer more redundant cues upon which to establish the congruence between two images. To take an extreme example, it is probably easier to establish congruence by comparing two views of a complex urban environment, than two views over a relatively featureless dessert.

The present investigation examined the issues of image (terrain) complexity and feature type (cultural vs. natural), but did so in the context of a different evaluation of map perspective from that examined by Hickox and Wickens (1996). Instead of comparing different elevation angles, our interest here was in comparing different scales or scopes of coverage. We made this comparison in the context of an assumption that constraints on map information uplinking constrained the imagery to accommodate only three maps, or three views of route between the initiation and final destination of the mission. We then contrasted two different means of rendering these three views, each based upon a different principle of human performance.

In what we call the **tiled** representation, based on the principle of consistency (Wickens, Gordon and Liu, 1998; Andre and Wickens, 1991), the total route is subdivided into three equal scale, 3D views, each providing coverage of non-overlapping areas along the flight path, much as three tiles on a kitchen floor might do. In this way, the viewing scale is consistent across all three maps (see Figure 1a). In what we labeled the **global-to-local** representation, based upon principles of perceptual analysis, the total route is depicted only on the first map. As the target is approached, a second map, at a higher level of detail, depicts only the remaining track to the target and later, a final map presents only the final third of the distance to the target at the highest level of detail (see Figure 1b). In this way the pilot is initially given a global perspective of the total mission, and as the mission progresses, more local detail is provided. The concept is based upon the perceptual principle of **global precedence** (Navon, 1977), which characterizes the way we examine images, first focusing on the overall form, and subsequently zooming into higher levels of more detailed analysis. At the top of the Figures 1a and 1b, the three views on the computer screen for each map type are shown to accommodate different views of the terrain patch, represented at the bottom.

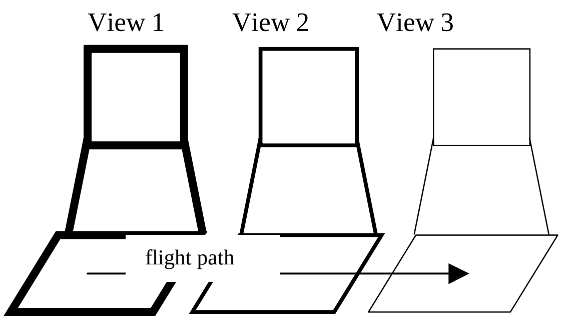


Figure 1a. Tiled mapping condition

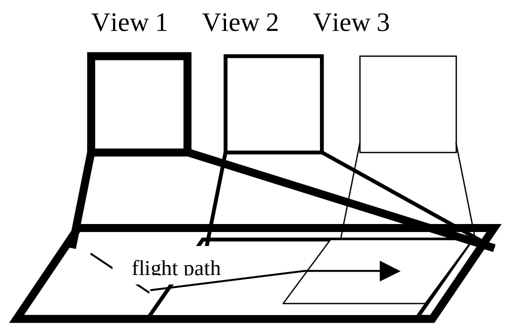


Figure 1b. Global-to-local mapping

Our pilots flew along a series of mission routes within a complex terrain database, used by Conejo and Wickens (1997). Some missions would take them from sparse into increasingly complex terrain in which the target was located; others would reverse, going from dense to sparse. We hypothesized that the global-to-local map might serve the sparse-dense paths better than the dense to sparse. We also hypothesized that navigation performance (based upon global image comparison) might be affected differently by complexity than target acquisition performance, based upon a serial search process. We manipulated feature type by varying whether the target itself was defined by cultural or natural features. Each flight was characterized by three "legs", depicted separately by each map in the tiled condition, and each characterized by a path and a final landmark. This landmark on the third leg served as the target of final capture.

Method

Participants

Seventeen pilots were recruited from the Institute of Aviation of the University of Illinois. All pilots were paid $6/hour for their participation in the study. The pilots ranged in total flight time hours from 100 to 360 hours with an average of 205 hours and ranged in age from 19 to 28 years with an average of 21 years. Fourteen pilots were male and 3 were female.

Apparatus

An Evans and Sutherland (E&S) SPX500 computer generated the environment. The scene was projected onto two 3.0 by 2.2 meter screens and viewed by the pilots from approximately 3.0 meters away. Visibility of the scene was set at 6 miles. A Silicon Graphics IRIS workstation generated the map and flight instrumentation. The map and flight instrumentation was presented on a 1024 x 1024 line color monitor, located about 2 ft from the pilot. The only flight instrumentation available to the pilots were an altimeter and a heading indicator. The subjects were seated in a chair with two-axis joystick mounted on the right arm. The joystick allowed control of the pitch and roll of the aircraft. Airspeed was held at a constant 400 knots. The joystick had two red buttons,

one for advancing the viewpoint of the forward field of view of the map along the path and one reviewing the 2D plan map of the mission and entire area.

Experimental Conditions

Map Type: Each flight mission was characterized by flying 3 legs to reach a final destination. Two map presentation types were employed for navigating through the environment shown in Figure 2. The **tiled mapping** was a track-up, perspective view display that depicted three separate but progressive views of the world along the flight path. Each map encompassed an area of 15 by 15 miles. The first map in the succession was a static depiction of the initial one-third of the mission including the objects along the path of the first leg in the mission. After the pilot advanced along the flight path and neared the target, he or she needed to call for the map depicting the second portion of the mission. Progressing toward the third and final leg that included the target destination, the pilot again needed to call for the map update.

The **global-to-local** (GL) presentation type was also a static and generally track-up map but increased in detail as the pilot progressed toward the final destination. At the onset of the trial, the map depicted the entire mission with all three legs presented to the pilot. The final destination target was centered at the top of this view, but the intermediate target and starting point may be located off center. This global view allowed the pilot to formulate a complete internal representation of the entire mission, but the distinct details of the individual features were unclear. As the pilot reached the target at the end of each leg, thereby getting closer to the final target, he or she would increase the detail of the environment by zooming in on the final target. For example, the second map showed only the second and final portions of the mission (again, the final destination target was centered at the top of this view). The third global-to-local map showed the third leg and final target destination of the mission and looked the same as the third map depicted by the tiled map. The final map representation of the global-to-local presentation was the same as the last and final map of the tiled mapping display.

The relationship between the two maps is illustrated in Figures 3 and 4, which portrays approximately the region depicted by the three panels on each map type during a typical approach. Achievement of the first and second targets (X) served as the cue for the discrete appearance of the next tile (tiled map) or the next zoom level (global-to-local). Note that the final map in both conditions is identical. All maps were static three-dimensional views forward from the entry point to the map. Ownship symbol was not depicted on either map. This forced the pilot to maintain eyes out on the E&S imagery, in order to navigate safely.

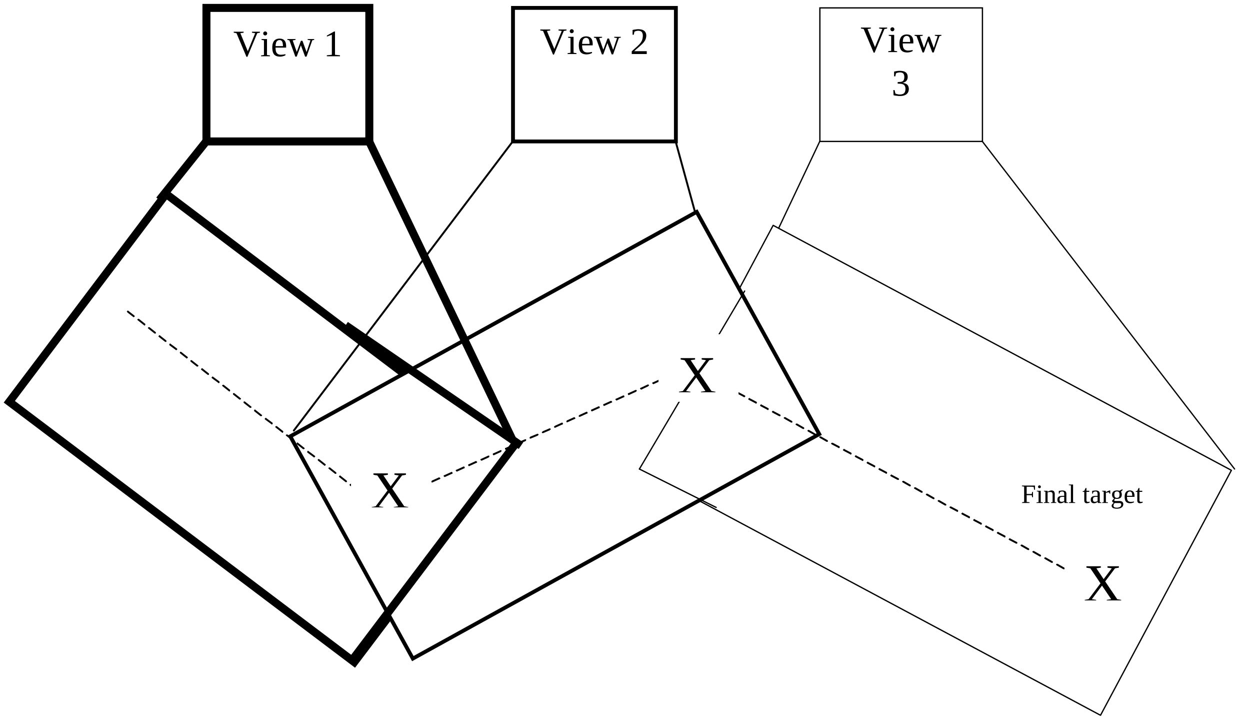


Figure 3. Three consecutive map views in the tiled condition, depicting the two lead-in legs and the final target.

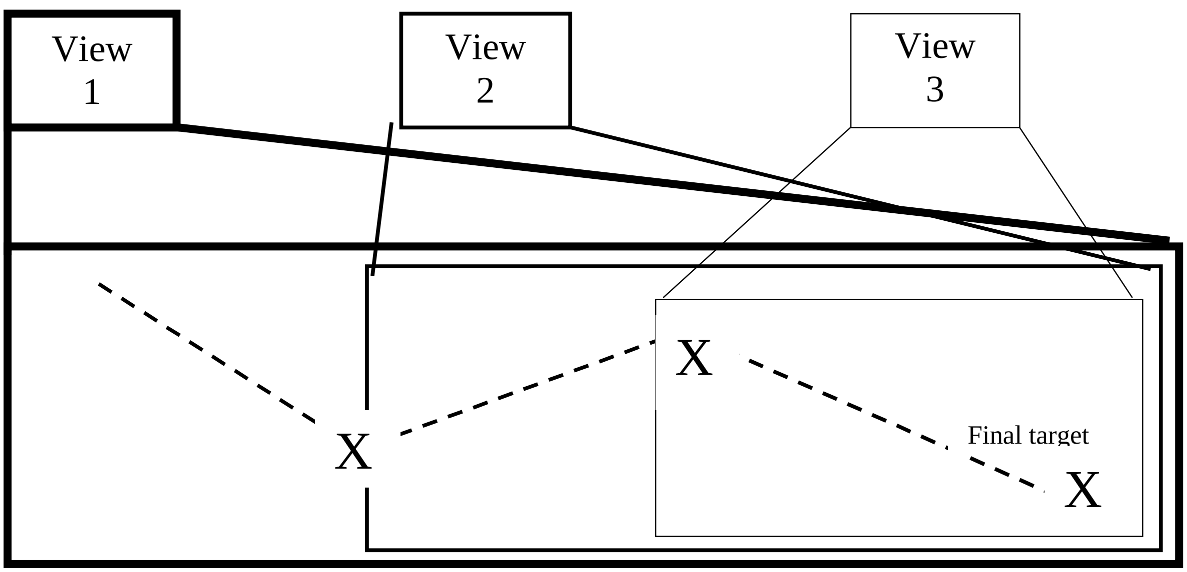


Figure 4. Three consecutive map views in the global-to-local mapping condition. Note that the size of the individual views is not to scale. Each view is of equal size, only the detail of the map changes.

Target (Feature) Type: The pilots navigated to two different target types, represented schematically by the Xs in Figures 3 and 4, either a natural feature of the environment or a cultural feature. The natural features consisted of rivers, lakes, mountains, and plateaus. The cultural features were man-made features such as oil refineries, airports, road or railroad intersections, and buildings. Our particular interest focused on the classification (natural or cultural) of the final target.

Complexity: The complexity of the map also varied depending on the pilot's location in the environment. Some areas of the environment were densely packed with both cultural and natural features, as seen in the lower left quadrant of the terrain depicted in figure 2, while other areas were barren with fewer features of either type. On half of the trials, the pilots flew out of the richly featured environment and into the more barren section of the world and in the other half of the trials the opposite situation was encountered.

Design

A 2 x 2 x 2 factorial design was employed to investigate the effects of map presentation type (tiled mapping, global-to-local zooming), feature type of the final target (natural, cultural), and complexity of the environment along the path (sparse-to-dense, dense-to-sparse). The order of presentation was counterbalanced.

Procedure

The experimental session began with the pilot completing a demographics form and reading the written instructions of the tasks. Each pilot received training on reading the maps and flying the aircraft. The experimental trials began after each pilot learned the task and successfully completed navigating to a practice target destination. The entire experimental session required each pilot to fly 24 missions. Each mission had 2 lead-in legs with either a cultural or natural feature marked to denote where a change in heading occurred.

At the beginning of the trial, the entire mission was displayed pictorially on a plan view map presented to the pilot for 10 seconds. The pilot's assigned flight path was depicted on the map, as well as the aircraft's approximate initial position. The pilot could refer back to this map at any time during the mission. Also, a verbal description of the feature and approximate heading for each leg of the mission were displayed on the monitor throughout the trial. Pilots were instructed that each heading was an approximation and to rely on cues from the environment. Again, this forced the pilot to maintain eyes out on the E&S imagery, in order to navigate safely.

Once the trial began, the perspective map was displayed in one of the conditions (global to local or tiled mapping). The pilot was instructed to fly at a constant altitude of 400 feet using pitch control. Once the pilot located the first target in the forward field of view, he or she could press a red button to advance the viewpoint of the map along the path. The view changed to the next region of space in the tiled condition or a zoomed-in version in the global-local condition. The pilot then changed heading and continued to fly toward the final destination. Once the pilot acquired the final target during the third leg, by centering a square reticle around the target's image in the forward field of view, he or she could pull a trigger on the joystick to end the trial.

At this time, accuracy was scored: correct if the reticle surrounded the target, error if it did not. If at any time the pilot became disoriented, the mission overview could be requested and the plan view map was displayed. The number of times the pilot requested the mission overview map was recorded.

A typical experimental session is shown in Table M1. Missions varied somewhat in the sharpness of heading changes and in their overall direction; however all missions were configured such that the three legs were generally in the same direction (e.g., heading 090 in Figures 3 and 4).

Block	**Mapping**	**Missions**	**Details**
1	Tiled Mapping	6 missions	3 Dense to Sparse/ 3 Sparse to Dense trials
2	Tiled Mapping	6 missions	3 Dense to Sparse/ 3 Sparse to Dense trials
		BREAK	
3	GL Mapping	6 missions	3 Dense to Sparse/ 3 Sparse to Dense trials
4	GL Mapping	6 missions	3 Dense to Sparse/ 3 Sparse to Dense trials

Table M1. Presentation of conditions for a typical experimental session. Approximately half the trials of each block terminated at cultural feature targets and half at natural feature targets.

Measurements

The dependent variables were chosen to assess pilot skill in target identification and navigation. Measures for target identification included the time to navigate to the final destination and accuracy in identifying the final destination (reported as error rate in the Results section). Navigation time was recorded from the beginning of the mission until the pilot pulled the trigger for the final target. This time was standardized to zero across all missions for the analyses, such that negative values correspond to faster response times. Navigation measures included mean absolute error (MAE) for altitude deviations from 400 feet, as well as lateral deviations from the desired heading. These were recorded for each leg of the mission. The number of times the overall mission (i.e., 2D map) was requested was also recorded. The pilots had a limited amount of time (four minutes) to reach each target per leg. If that period of time expired, the pilot was automatically moved to the target and the trial continued from that point.

Results

Three sets of analyses were carried out on the data. The first was to establish the effect (if any) of the counterbalancing order in which subjects received the two map types, and to determine if there was any asymmetric transfer between them.

The second and third analyses examined the effects of the critical map and environmental variables, each from a slightly different perspective. The second set of analyses examined the effects of map type, complexity order (sparse-to-dense vs. dense-to-sparse) and final target feature type (natural vs. cultural), using the average performance across the whole flight as independent variables.

The third set examined the effects of map type, complexity order and feature type, on the independent variables measured for the third leg of the mission (rather than averaged across legs, as in the second set of analyses). It will be recalled that the final map representation of the global-to-local presentation was the same as the last and final map of the tiled mapping display.

Finally, each of the second and third analyses consisted of two separate ANOVAs: (1) a univariate ANOVA conducted on the accuracy of target detection (this variable consisted of the accuracy of the target on the final leg of the mission for both analyses), and (2) A multivariate MANOVA on the vector or vertical tracking error, lateral tracking error and standardized response time to target detection. Where the MANOVA revealed a significant effect, we report the separate components that contributed to that effect.

First Analyses: Order and Block Effects

Although performance was essentially the same for the first and second blocks of the experiment, the order in which subjects received the two map types had a significant impact on their tracking and RT performance. Subjects starting with the GL map were faster in identifying targets and had less error in lateral tracking (Rao R (3,12); $p<.01$). Accuracy in identifying targets was not affected by order ($F(1,14)=.78$; $p<.38$), but there is a hint of an improvement for the second block ($F(1,14)=2.53$; $p<.11$). See Figures 5a, 5b, 5c, 5d.

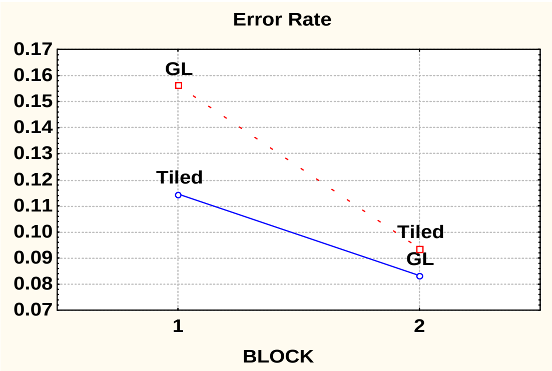


Figure 5a. Error Rate.

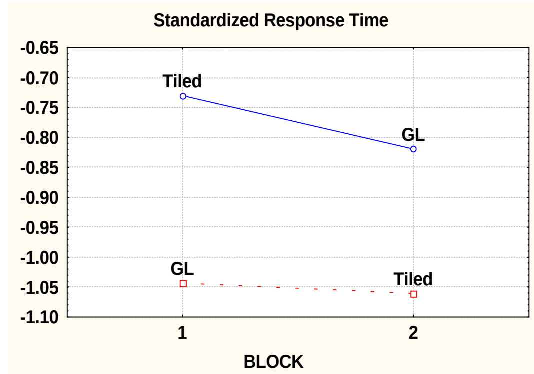


Figure 5b. Response Time.

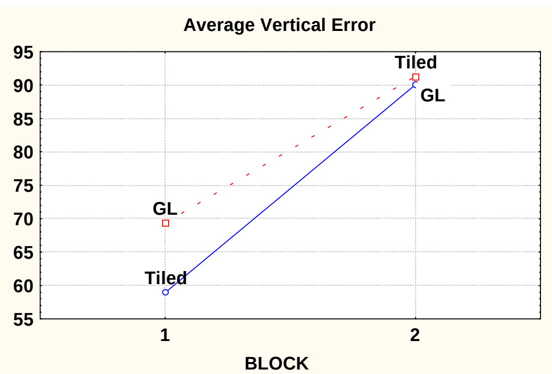


Figure 5c. Average Vertical Error.

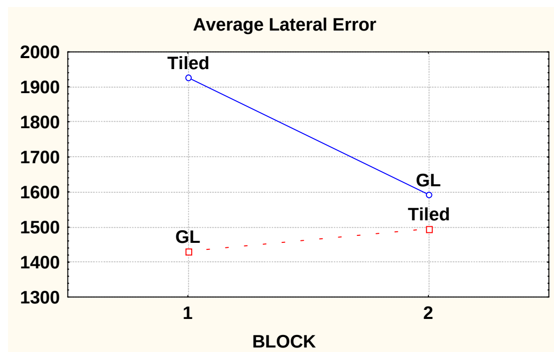


Figure 5d. Average Lateral Error.

<u>Second Analyses: Effects Averaged Over the Mission</u>

In the second analysis, tracking error scores refer to the average across the full 3 legs, while target acquisition scores (i.e., accuracy and RT) are reported only for performance at the final destination.

A significant density effect was found for all dependent measures (i.e., accuracy: $F(1,15)=7.30$, $p<.01$; RT/vertical/lateral error: $R(3,13)=3.63$, $p<.01$). As shown in Figures 6C and 6D, further analysis revealed travelling from a sparse to dense environment generally hurt vertical tracking and accuracy in identifying the final target, but it helped lateral tracking performance. The negative effect of sparse-dense on target detection error rate, shown in figure 6A, can be interpreted in terms of the fact that the final target was detected within the dense quadrant of the map.

In addition, a significant interaction was found between density and map type for RT and tracking performance ($R(3,13) = 2.37$; $p<.07$). Tracking performance was differentially affected by the combination of map type and complexity of the environment. Vertical tracking was adversely affected by sparse-to-dense terrain and the GL map, while lateral tracking was adversely affected by dense-to-sparse terrain and the Tiled map. Furthermore, no influence was

found in vertical tracking for the Tiled map, nor in lateral tracking or target identification response time for the GL map. See Figures 6a and 6B.

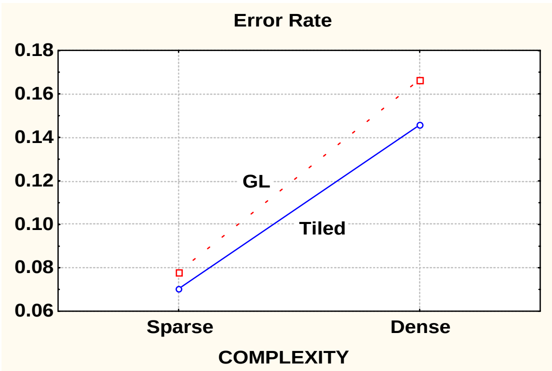


Figure 2a. Error Rate.

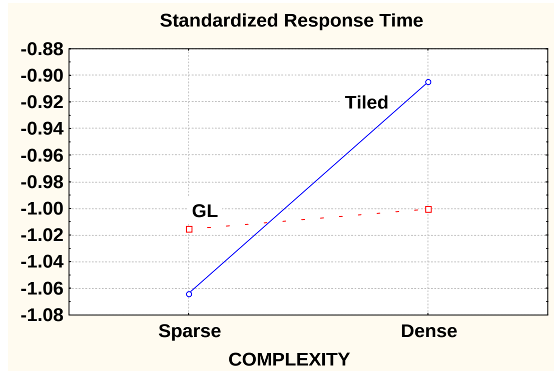


Figure 2b. Standardized Response Time.

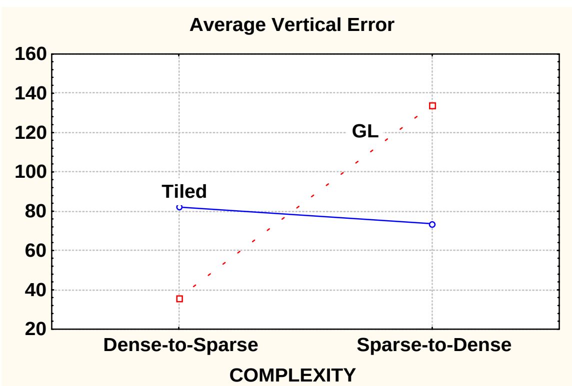


Figure 6c. Average Vertical Error.

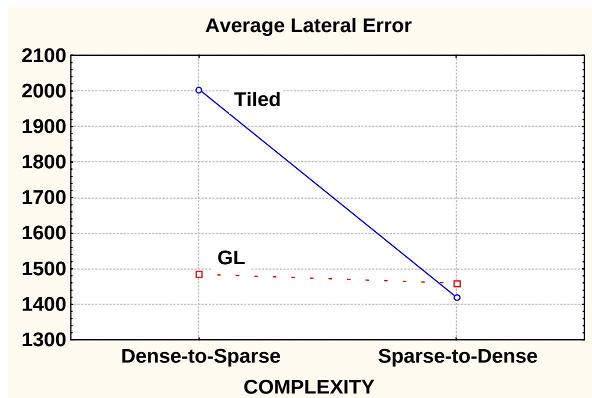
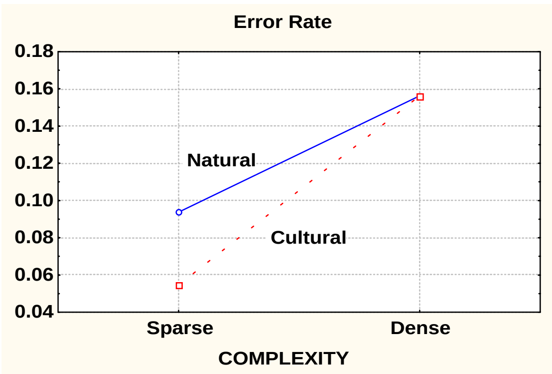


Figure 6d. Average Lateral Error.

Although there was no main effect of map type, this variable did interact with the density order as portrayed in figure 6 (R 3,13 = 3.63; p<.01). The effects of the three dependent variables within this interaction were as follows: the cost for target identification response time in the high density third leg, was only observed in the tiled map (Figure 6b); a cost to vertical tracking on sparse–dense maps, was only observed for the global-local map type (Figure 6c); a cost to lateral tracking on dense-sparse maps, was only observed for the tiled map. As Figure 6a suggests, map type had no influence, either directly or in interaction, on target error rate.

Target feature type was also found to independently affect RT and tracking performance (R(3,13)=51.1; p<.001), as well as to significantly interact with terrain complexity for these same three measures (R(3,13)= 2.37; p<.068). As shown in Figure 7a, pilots had more errors in identifying targets embedded in sparse terrain. In addition, the final target was detected and located more rapidly when it was a natural feature (Figure 7b). Furthermore, as shown in Figure 7d, the pilots' lateral error was less, when flying to landmarks that were primarily natural. A similar benefit to vertical tracking to natural features was found (Figure 7c), but only when flight was proceeding from sparse to dense terrain. Further analysis indicated vertical error is only

reduced with the combination of a natural final target and travelling from a sparse to dense environment. A cultural feature, however, showed a density cost in terms of average vertical error. See Figures 7a, 7b, 7c and 7d.



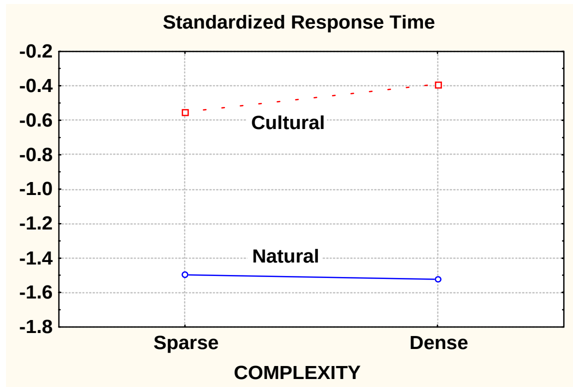
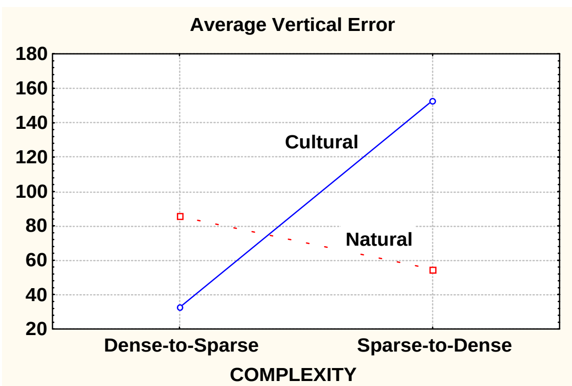


Figure 7a. Error Rate.

Figure 7b. Standardized Response Time.



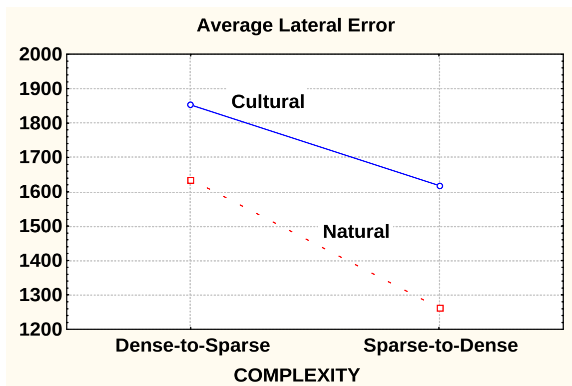


Figure 7c. Average Vertical Error.

Figure 7d. Average Lateral Error.

Third Analyses: Effects by Each Leg of the Mission

An examination of the independent variables measured by each leg of the mission revealed only the third leg with any significant differences in performance, namely vertical and lateral tracking. Target acquisition results (i.e., accuracy and response time) for the final leg were reported earlier. Mean tracking error for these variables is broken down by leg in Tables 1-6. Note the final map representation of the GL condition was the identical to the final map of the Tiled condition. Within the table, it should be noted that leg 1 was always either sparse or dense, leg 3 was always the opposite, and leg 2 was a transition leg, typically involving a mixture of sparse and dense terrain. To aid visualization of the trends in the data, each measure within dense terrain is **boldfaced**.

	Leg		
Complexity	**1**	**2**	**3**
Dense-to-Sparse	**123**	173	139

	Leg		
Complexity	**1**	**2**	**3**
Dense-to-Sparse	**713**	2156	3061

Sparse-to-**Dense**	105	171	**182**

Table 1. Vertical Error.

Sparse-to-**Dense**	462	1821	**2217**

Table 2. Lateral Error.

	Leg		
Feature	**1**	**2**	**3**
Cultural	108	161	186
Natural	120	184	135

Table 3. Vertical Error.

	Leg		
Feature	**1**	**2**	**3**
Cultural	495	2218	3013
Natural	680	1759	2265

Table 4. Lateral Error.

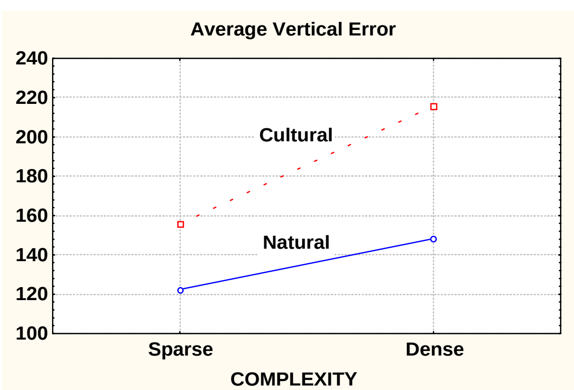
	Leg		
Map Type	**1**	**2**	**3**
GL	114	172	166
Tiled	114	172	155

Table 5. Vertical Error.

	Leg		
Map Type	**1**	**2**	**3**
GL	605	1803	2388
Tiled	569	2173	2890

Table 6. Lateral Error.

This set of analyses showed that as pilots completed the final leg of the mission, the complexity of the terrain and the target feature type would independently affect their performance. The interaction between complexity and feature was not significant for these dependent measures. High density on the third leg of the mission led to mixed results. Pilots had poorer performance in vertical tracking, yet better performance in lateral tracking ($R(3,13) = 5.34$; $p<.001$). When the final target was defined by natural features, vertical and lateral tracking error was reduced ($R(3,13) = 18.01$; $p<.000$), as shown in Figures 8a and 8b.



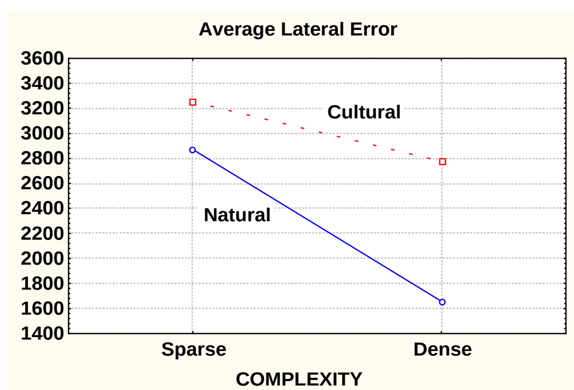


Figure 8a. Average Vertical Error.

Figure 8b. Average Lateral Error.

Post-Experiment Questionnaire

The pilots' preference overwhelmingly favored Tiled maps. Furthermore, some pilots indicated they had a more difficult time learning the GL map, as compared with the Tiled map. Other reasons cited for the Tiled map preference included its consistent orientation with pilots' view of the world, its simplicity, and its greater detail for the first two maps presented.

Overview of Results

In spite of pilot preference for the Tiled maps, some performance evidence appears to favor the Global-Local format. In particular, the data indicate that subjects who used the GL map first, had a significant advantage during the first half of the experimental trials, over those using the Tiled map on their first trials. This advantage disappeared, but did not reverse during the second half of the experiment.

The second and third sets of analyses suggested some slight advantages for the GL map, and also that the complexity of the environment accounted for two major effects on performance. On the one hand, high terrain density made target acquisition more difficult. On the other hand, density enhanced navigation performance (i.e., fewer lateral errors). The post-experiment subjective results also generally indicated that high density was preferred. The additional cues in the dense terrain were cited as more realistic and helped orient the pilot.

Finally, natural features enhanced performance in most areas as compared to cultural features, although this trend was not found in the subjective data, which indicated that subjects equally preferred natural and cultural features. The influence of map type was more complex. The GL map led to faster response times in dense terrain and less lateral error in travelling to sparse terrain than the Tiled map. There was no advantage for the GL map in terms of target identification accuracy and there was a density cost for the GL map associated with vertical tracking. Overall, there were more performance costs associated with using a Tiled map.

Discussion

Maps

The evidence for superior performance of one map over another is not strong, and the data did not support our original hypothesis that global-local formatting would be particularly beneficial on sparse-dense missions. Where some differences between map formats did appear to emerge however, they tended to favor the global-local format over the tiled format, particularly in supporting better lateral tracking performance in the dense-sparse routes (Figure 6d), and in the earlier trials of the experiment (Figure 5). This performance trend appeared to be at odds with pilot preferences, which favored the Tiled map.

Some diagnosis of the differences between the two maps can be gained by considering the learning data in more detail, shown in Figure 5. As the figure shows, subjects who started with the GL map had a significant RT and navigation advantage during the first half of the trials over those who had the Tiled map first. We can explain this by considering that subjects were slightly more prone to getting lost in the first half of the experiment than the last half. Furthermore, lost subjects using the Global-Local map could still accurately navigate to the final target, the only costs would be increased lateral error and response time. Lost subjects using the Tiled map would have less of an idea of the overall environment they were in and would thus be more susceptible to the RT and navigation costs. A lost subject in the GL condition, however, would have a better overall picture of the environment and would get to the final destination

faster and with less lateral error. Subjects were less likely to get lost in the second half of the experiment, such that these "lost costs" were less pronounced.

Another explanation for why subjects in the Tiled first condition never improve their RTs to the same level as subjects in the GL first condition is that the former subjects had a more difficult time switching. The vast majority of subjects favored the Tiled map, and its overall simplicity is among the many reasons cited for this favoritism. Subjects starting with this simplicity had more trouble switching to the GL map because it was often incongruent with their forward field of view and thus it required more effort to use. On the other hand, subjects starting with the GL map had no trouble switching to the easier, more straightforward Tiled map.

Finally, the large cost in lateral tracking found for the Tiled first condition may also be partially explained by these subjects using each view of the Tiled map as a range of error for navigation performance. This is analogous to a problem with the tunnel in the sky display. The tunnel is perceived by pilots as a rough guide (e.g., a box) for navigation with room to err, as opposed to a precise display for guiding aircraft. In the same way, the Tiled map may be viewed by pilots as "accurate enough" to guide their navigation. When pilots later switched to the GL map, there was no "tunnel" for tracking. They were forced to use the 2D plan map in order to know what their flight path was. In other words, the flight path was intrinsically displayed on the Tiled map, with its final destination centered at the end of each view but it had to be deduced on the GL map. The reason that the subjects switching from GL to Tiled don't show the same lateral error with the Tiled map is that they are unlikely to change strategies when their initial reliance on the 2D map still worked. This may also explain why pilots overwhelmingly favored Tiled maps: they had to switch to the 2D map fewer times.

Density

More robust results were uncovered in terms of density effects, suggesting a tradeoff between performance in vertical and lateral tracking. When the final target region was dense, vertical tracking performance was hurt, but lateral tracking performance was helped. Consistent with Hickox and Wickens (1996), these results suggest that a dense environment provides more cues and allows pilots to estimate a more accurate flight path along the terrain. Furthermore, target acquisition is hindered in a dense environment, due to delays in serial search time and confusability of targets.

Another explanation for the density effects may be due to the different sources of information for the tasks that generate these two performance measures. For example, the only source of altitude information .the altimeter) was located on the map (i.e., head down), while information on heading was primarily available in the world (i.e., head up). Hence, anything that pulled the eyes up would have to hurt any aspect of head down performance, namely altitude control. A richer, more complex environment intrinsically induces pilots to keep their eyes up and out, in order to maintain the flight path (and consequently, to have fewer lateral errors), and target search amidst the greater amount of clutter. Thus, the tradeoff between performance in vertical and lateral tracking is much more pronounced in the denser environment. While it could be argued that some heading information was also available on the map, we assume that this source of information was not extensively consulted, since pilots were instructed that the heading

information should be considered a rough estimate and could be up to 10 degrees off. Pilots were instructed instead to rely on cues in the environment for navigation purposes.

Feature

In general, natural features led to faster response times and better lateral navigation. Natural features consisted of lakes, mountains, plateaus and rivers. All of these items encompassed a large, distributed area. Cultural features (e.g., antennas, water towers, intersections), on the other hand, generally encompassed a smaller, more discrete area. Thus, the bigger natural targets were easier to see and pilots were able to respond sooner to these targets, evidenced by the faster RTs. Likewise, being able to see the final target helped pilots maintain their flight path (i.e., less lateral error). It gave them a direct line of sight to guide the aircraft.

It could be argued that pilots would not use the final target (whether cultural or natural) as a navigational guide, but they should instead respond immediately to end the trial upon seeing the target. Although this is true of the smaller cultural targets, this is probably not the case for natural targets. Due to their larger size, natural targets were defined more explicitly. For example, pilots had to seek the north-west tip of the mountain. Pilots had to have the precise point in the reticle before responding. Thus they would still be able to use the natural feature (mountain, in this case) to guide them in.

Although natural features helped in these areas, it actually hurt target identification accuracy. This may be explained by the size and the definition of targets, as discussed previously. Since natural targets were larger objects, they were defined explicitly (e.g., north-west tip of mountain). Cultural targets were more generally listed (e.g., intersection of roads). Pilots had to seek the appropriate target point before responding in both circumstances. In the case of the larger natural target, there was more room for error and confusion, hence the higher error rate. It was less confusing for pilots to identify the cultural targets. These targets were either seen or not, there was no need to process further where the objective point was located.

In conclusion, the results of the current experiment suggested that pilots could navigate adequately with either map format; but certain characteristics, particularly those of a less familiar environment (i.e., the first half of the experimental trails), might favor a global-local concept. The data suggest the continuing relevance of both complexity and feature type distinction, in navigation and target acquisition performance, as had been revealed in our earlier work (Conejo and Wickens, 1997; Hickox and Wickens, 1996). The effects of these variables remain to be well modeled; but their continued importance in the use of electronic maps cannot be disputed.

References

Andre, A.D., and Wickens, C.D. (1992). Compatibility and consistency in display-control systems: Implications for aircraft decision aid design. *Human Factors, 34*(6), 639-653.

Conejo, R.A., and Wickens, C.D. (1998). The effects of highlighting validity and feature type on air-to-ground target acquisition performance. *Proceedings of the 16th Biennial Applied*

Behavioral Sciences Symposium. USAF Academy, CO: Dept. of Behavioral Sciences & Leaderhsip.

Conejo, R., and Wickens, C.D. (1997). *The effects of highlighting validity and feature type on air-to-ground target acquisition performance*. University of Illinois Institute of Aviation Technical Report (ARL-97-11/NAWC-ONR-97-1). Savoy, IL: Aviation Res. Lab.

Hickox, J., and Wickens, C.D. (1996). *Navigational checking: A model of elevation angle effects, image complexity, and feature type*. University of Illinois Institute of Aviation Technical Report (ARL-96-4/NAWC-ONR-96-1). Savoy, IL: Aviation Res. Lab.

Navon, D. 91977). Forest before the trees: The precedence of global features in visual processing. *Cognitive Psychology*, *9*, 353-383.

Schreiber, B.T., Wickens, C.D., Renner, G. J., Alton, J., and Hickox, J.C. (1998, in press). Navigational checking using 3D maps: The influence of elevation angle, azimuth, and foreshortening. *Human Factors*.

Wickens, C.D., Gordon, S., and Liu, Y. (1998). *An introduction to human factors engineering*. New York: Addison Wesley Longman, Inc.